TEM Horn Antenna using Improved UWB Feeding Mechanism

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***Abstract*—In this paper, CST-MS was used to model and simulate an Ultra wideband TEM horn antenna using an UWB feeding mechanism. Model views are shown and the results of frequency domain simulation up to 5 GHz are plotted for the UWB TEM horn antenna. The feed and the TEM horn were simulated for various characteristics like frequency domain reflections, VSWR, insertion loss, radiation pattern and gain etc. The half power beamwidth and antenna factor of the antenna were also calculated. The antenna is wideband, non dispersive, directive and has low VSWR.**

I. INTRODUCTION

The most common type of horn is a waveguide horn in which the energy is confined in all dimensions in the waveguide modes. However, in waveguide the wave velocity is the function of frequency. The time of arrival of a transmitted pulse in the horn aperture is the function of the frequency resulting in the dispersion. In addition these horns, when smooth walled, are restricted in bandwidth to about 1.8:1 for the rectangular cross section and 25% for the circular cross section by the possibility of generating unwanted higher order modes. Other types of the waveguide horn such as corrugated and dielectric lined are also restricted in bandwidth to less than 2:1 by higher order modes. In contrast a TEM horn (fig.1) is a flared TEM transmission line based on a parallel plate transmission line. It makes use of the propagation of all frequencies. All frequencies generated at the horn throat will arrive at the aperture together, and therefore a wideband pulse is transmitted from the aperture. Here in this paper a corrugated stepped horn type of antenna for the propagation of electromagnetic energy having a modified structure for the reduction of back lobes and side lobes in the radiated beam by controlling the illumination of the E-plane edges. Specifically, the control of illumination of the E-plane edges is achieved by electrically modifying the walls of the horn having an E-plane edge as an element. The TEM horn antenna is one of the most popular antennas for impulse-radiating applications, due to its low phase distortion and wide frequency bandwidth.

II. TEM HORN ANTENNA

A. Modes in a Parallel Plate line

A parallel plate line is described in terms of the geometry of its cross section at any point. The modes in a parallel plate guide of height b may be regarded as appropriate limiting forms of modes in a rectangular guide of height b as the width a of the latter becomes infinite. The modes in a rectangular guide of height b and width a form a discrete set. However as the width of the rectangular guide becomes infinite the corresponding set of modes assume both a discrete and continuous character. The mode index n characteristic of the mode variation along the y dimension is discrete whereas the index m characteristic of the variation along the x direction becomes continuous. The complete representation of the general field in the parallel plate guide requires both the discrete and continuous modes. The discrete E-modes in a parallel plate guide of height b are derivable from the scaler functions.

$$\phi_i = \sqrt{\frac{\varepsilon_n}{b}} \frac{\sin\frac{n\pi y}{b}}{\frac{n\pi}{b}}, 0 < y < b \tag{1}$$

$$n = 0,1,2,3,\ldots\ldots\ldots\ldots, \varepsilon_n = 1$$

for n=0 and ε_n =2 for n>0

The cut-off wavelength of the E_{0n} mode in parallel plate guide is λ_c =2b/n.The E_{00} mode or the TEM mode is the principal mode in the parallel plate guide. The principal mode is characterized by an infinite cut-off wavelength λ_c and hence a guide wavelength λ_g identical with the space wavelength λ. The parallel plate line propagates only TEM mode if operating frequency is such that λ <2b.

B. Design Criteria for the TEM horn

The characteristic impedance of a parallel plate line depends upon the ratio of the distance between plates b and the width of the plates a. For the present TEM horn design any higher mode is undesirable because for higher order modes the velocity along the structure is a function of frequency leading to dispersion. Also the radiation pattern of these higher order modes is not the same as TEM mode. The limit on b is the most important at the excitation point as once the TEM mode is established no higher mode will be generated unless a disturbance to wave propagation is met. The parameter needed to design a TEM horn are the required aperture of the horn, input line impedance and the bandwidth. The aperture size of the TEM horn is constrained by the desired gain and the length of the horn. The impedance of the TEM horn is determined by the feed from the generator to the horn. There is no lower cut off frequency for the TEM horn, however the feed used for the horn may have effect on the lower cut off frequency. The upper cut off frequency of the TEM horn is constrained by the generation of the higher order modes. To avoid higher order modes at the feed point the separation between the plates at the feed point has to be less than a wavelength at the highest frequency of operation .The feed used may also have an effect on the upper cut off frequency.

1) Impedance Tapered TEM horn: The problem with a constant impedance TEM horn is large reflections at the aperture when Z is small and difficulty in designing a proper feed when Z is large. So it was decided to go in for a taper in impedance from throat to aperture. Sudden changes in the line impedance along the horn would generate reflections. To avoid these reflections, the aspect ratio must be changed slowly. In the designed TEM horn the sudden changes in the impedance and thereby reflections have been kept low by changing the impedance of the TEM horn in such a way that the reflection coefficient along the length follows a Tschebyscheff taper (fig.2). The separation between the plates should also be almost constant towards the feed end to allow the field to settle down. Also a large aperture size is desired for higher gain. These contradictory requirements were met by following an exponential taper for the separation between the plates. The reflections at the aperture have been minimized using rolled edges.

2) Design of Impedance Tapered TEM horn: The values selected for the impedance taper for the design were 100 ohms at the feed point (to match it to the designed balun) and 250 ohms at the aperture. The impedance at the aperture was restricted to 250 ohms, because for higher impedance values, the separation to the width ratio is quite high and this will decrease the aperture area leading to lower gain. The impedance taper followed was Dolph-Tschebycheff (same as balun).However; the taper was slightly modified to avoid discontinuities at the ends.

Once the impedance taper to be achieved has been obtained, the required separation to the width ratio (aspect ratio) for this impedance taper was calculated. The separation between the plates at the feed point was taken as 3.2mm,so as to achieve possible upper cut off frequency in excess of 4GHz.The separation between the plates at the aperture was taken as 300mm,so as to obtain reasonable gain. The length of the TEM horn was taken as 84 mm. Then the required separation between the plates along the length of the TEM horn was calculated so as to get exponential taper. This was done so that the increase in separation is less in the beginning (at the feed point) allowing the TEM mode to settle down and more at the aperture in order to obtain higher gain. Having fixed the separation between the plates the corresponding width of plates was calculated from the separation to width ratio.

3) Corrugated Pyramidal Horn: A corrugated (grooved) pyramidal horn, with stepped corrugations on the E-plane walls, is shown in fig 1. To form a very effective corrugated surface, more than 10 slots per wavelength are made. To simplify the analysis of an infinite corrugated surface, the following assumptions are made

i) The teeth of the corrugations are vanishing thin.

ii) Reflections from the base of the slot are only those of the TEM mode.

The surface reactance of the stepped corrugated surface, used on the walls of the horn, are capacitive in order for the surface to force to zero the magnetic field parallel to the edge at the wall. Thus the surface will not support surface waves, thereby preventing illumination of the E-plane edges, and will diminish diffractions.

TABLE I

ANTENNA: FLARED TEM HORN

Distance along TEM Horn (cm)	**Impedance along the TEM Horn (ohms)**	**Separation between the Plates (mm)**	**Width of the Plates (mm)**
0	100	3.2	8.2
8	106	4.93	11.63
16	114.45	7.6	16.16
24	126.89	11.71	21.5
32	141.87	18	27.54
40	159.55	27.8	35
48	179	42.85	43.1
60	208.78	81.96	64.48
72	233.937	156.8	100
84	250	300	167.3

III. WIDE BALUN FOR TEM HORN

In order to match the balanced antenna impedance to the unbalanced impedance of the coaxial line, a balun transformer is required. Moreover, the balun transformer must be capable of operating over a large frequency range if it is compatible to the antenna. For this purpose a Tschebycheff tapered balun transformer is used.

1) Coaxial Transmission-Line Taper: For the purpose of balun for this TEM horn an impedance taper from 50 to 100 ohms was selected. The value of ρ_o for use in the design of the taper is calculated as $\rho_o = 0.5 \ln(100/50) = 0.34657359$. It will be required that the maximum reflection coefficient in the pass band shall no exceed one-tenth of ρ_o. Thus cosh (A) = 10.

The length of the balun is determined by the lowest operating frequency and the maximum reflection coefficient which is to occur in the passband. The balun has no upper frequency limit other than the frequency where higher order coaxial modes are supported or where radiation from the open wire becomes appreciable.

The length of the balun is calculated from $\beta l \geq A$ and for the present design cosh(A)=10 i.e. A=3. which gives required length = 0.478λ.

For this design, the lower frequency was selected as 400 MHz (λ = 75 cm). Thus the required length of balun is 35.85cm.

The characteristics impedance contour can now be obtained directly from equation given below

$$\ln(Z_0) = \frac{1}{2}\ln(z_1 z_2) + \frac{\rho_0}{\cosh(A)}(A^2 f(2x/l, A) + U(x - \frac{l}{2}) + U(x + \frac{l}{2})), Abs(x) \leq \frac{l}{2} \quad (2)$$

$$= \ln(z_1), x < -l/2 \quad (3)$$

$$= \ln(z_2), x > l/2 \quad (4)$$

U is the unit step function. And f is defined by

$$f(Z,A) = -f(-Z,A) = \int_0^z ((I(A\sqrt{1-y^2})/(A\sqrt{1-y^2}))dy \quad (5)$$

For Abs(Z) ≤ 1 and $\rho_o = 1/2\ln(z_2/z_1)$.The quantity ρ_o is determined by the two impedances to be matched, and A is selected on the basis of the allowed maximum reflection coefficient magnitude in the pass band.

2) Characteristic Impedance of Slotted Coaxial Line: The computed impedance taper is realized in the balun by removing appropriate parts of the outer conductor along the coaxial length. This requires knowledge of the characteristic impedance of a uniform, slotted coaxial line as a function of the slot angle. This was given by Duncan and Minerva in the form of upper bound & lower bounds to the exact characteristic impedance [6]. The upper bound is given as :

$$Z_0 = \frac{1}{2\pi}\sqrt{\frac{\mu}{\varepsilon}}\ln(b/a) + \frac{\sqrt{\frac{\mu}{\varepsilon}}}{\pi(\pi-\alpha)^2}\sum_{n=1}^{\infty}\frac{\sin^2(n\alpha)(1+\frac{c_n^{\ 2}}{n^2-k^2})^2}{n^2\left(1+\coth(n\ln\frac{b}{a}\right)} ohms \quad (6)$$

where

$$-c = \frac{\sum_{n=1}^{\infty}\frac{\sin^2(n\alpha)}{n(n^2-k^2)\left(1+\coth(n\ln\frac{b}{a}\right)}}{\sum_{n=1}^{\infty}\frac{n\sin^2(n\alpha)}{(n^2-k^2)^2\left(1+\coth(n\ln\frac{b}{a})\right)}} \quad (7)$$

$$k = \frac{\pi}{\pi-\alpha}, \quad (8)$$

b is the outer conductor dia
a is the inner conductor dia
α is half the slot angle

The lower bound is given as:

$$Z_0 = \frac{\frac{1}{2\pi}\sqrt{\frac{\mu}{\varepsilon}}\ln(b/a)}{1-(4/5)(\alpha/\pi)c} ohms \quad (9)$$

where

$$\frac{1}{c} = \frac{4}{5}(\frac{\alpha}{\pi}) + \frac{40}{\pi}\ln(\frac{b}{a})\sum_{n=1}^{\infty}\frac{(1+\coth(n\ln\frac{b}{a}))}{n\alpha}(\frac{A_n\cos(n\alpha)-B_n\sin(n\alpha)}{(n\alpha)^4}) \quad (10)$$

$$B_n = 3(n\alpha)^2 - 6$$

$$A_n = (n\alpha)^3 - 6(n\alpha)$$

These formula for upper bound & lower bound of characteristic impedance were programmed and the values obtained (for impedance values of interest i.e. 50 to 100 ohms) for the coaxial cable (relative permittivity = 2.7, b= 6.2mm, a= 1.2mm).

Subsequently the angle 2α along the length of balun required for 50 to 100 ohm Dolph Tschebycheff impedance taper was interpolated from the tables. For these calculations the mean value of the upper bound & lower bound characteristic impedance was used.

IV. RESULTS

The structure used in this design is shown in Fig. 1. The model is constructed in CST-MS and was used to simulate the antenna.

TABLE II
TSCHEBYCHEFF TAPER FOR BALUN DESIGN

X/l	Angle 2α(degrees)	X/l	Angle(2α)
-0.5	67.42	0	226.258
-0.475	72.42	0.025	232.633
-0.4	99.33	0.1	250.047
-0.375	107.78	0.125	255.266
-0.35	116.29	0.15	260.195
-0.275	141.25	0.225	273.204
-0.20	166.77	0.3	283.6
-0.175	174.84	0.325	286.69
-0.15	182.81	0.35	289.37
-0.125	190.6	0.375	291.879
-0.025	219.62	0.475	299.618
0	226.258	0.5	300.79

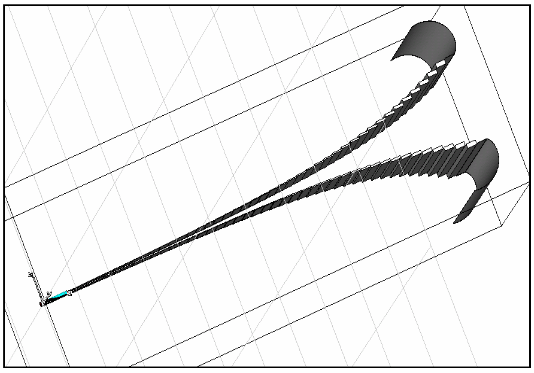

Fig. 1 Structure of the UWB TEM horn antenna alonghwith UWB feeding mechanism

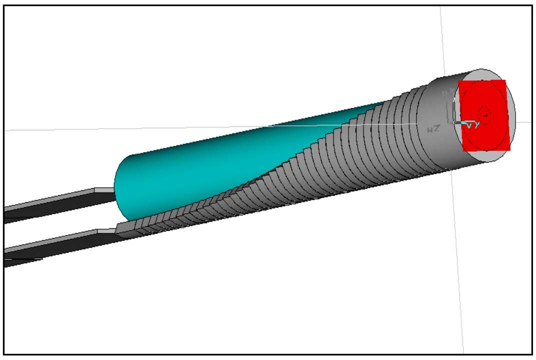

Fig. 2 Structure of the UWB feeding mechanism: Tschebycheff tapered balun

The reflection coefficients of the antenna are shown in the fig 3. The corresponding VSWR for this antenna for the frequency range of 500 MHz to 6 GHz can be seen from the fig 4. The gain of the antenna at 2.55 GHz is shown in the fig 5. The measured E-plane far-field pattern for this antenna, excited at 2.55 GHz is shown in Fig 6. This fig shows the antenna with a symmetric far-field pattern.

V. CONCLUSIONS

An UWB TEM horn along with its UWB balun feed is designed and simulated in CST-MS for frequency range in 500 MHz to 5 GHz range. The feed and the TEM horn were simulated for various characteristics like frequency domain reflections, VSWR, insertion loss, radiation pattern and gain etc. The half power beamwidth and antenna factor of the antenna were also calculated. The antenna is wideband, non dispersive, directive and has low VSWR. The non dispersive and ultra wideband characteristics make this antenna suitable for many other applications were the main requirement is pulse optimised wideband antenna. Therefore this antenna can be used in applications of pulse RADAR in collision avoidance, docking, and detection of objects buried in lossy materials (e.g. mine detection), detection of stealth targets and WB receptions required in electronic intelligence (ELINT) and electronic warfare (EW). In addition such antenna is useful in satellite communications were space & weight are conserved by supporting many communication channels with only one antenna. This WB antenna can also be considered for replacement of a large set of narrowband antennas in RCS range for wideband RCS measurements.

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REFERENCES

[1] N. Marcuvitz “Waveguide Handbook” McGraw Hill Book Co. Inc. ,Newyork,Ch 1,pp 7,1951.

[2] A W Rudge , K.Milne, A.D. Olver , P.Knight, ”The Handbook of Antenna Design” vol.2,pp 884-887,Peter Peregrinus Ltd,1983.

[3] Morton, ”On the parallel plate Condenser and other two dimensional fields specified by elliptical functions,” Phil. Mag ,2,1926,pp 827-33.

[4] P.Grivet, ”The physics of transmission lines at High and very high frequencies,” vol.1,Academic Press,1970.

[5] J D Taylor, Introduction to Ultra wideband Radar systems, pp 176-183,CRC,1995.

[6] J.W Duncan and V P Minerva, “ 100:1 Bandwidth Balun Transformer ,” Proc IRE vol 48,pp 156-164,Feb 1960.

[7] R.W. Klopfenstein, “ A Transmission Line taper of improved design” Proc. IRE. Vol.44,pp31-35,Jan 1956.

[8] R.E Collin , “ The optimum tapered transmission line matching section” , Proc. IRE. vol,44,pp 539-548,Apr 1956.

[9] J. H. Craven, “A Novel Broad-Band Balun,” *IEEE Transactions on Microwave Theory and Techniques,* MTT-14, 3, March 1966,pp. 112-119.

[10] P. R. Foster and S. M. Tun, “A Wideband Balun from Coaxial Line to TEM Line,” *Proceedings ofICAP.95, Ninth International Conference on Antennas and Propagation,* (Conf. Publ. No. 407),4-7, April 1995, pp. 286-290.

[11] J. D. Dyson, “The Unidirectional Equiangular Spiral Antenna,” *IEEE Transactions on Antennas and Propagation,* AP-7, 4, October 1959, pp. 329-334.

[12] P. J. B. Clarricoats and A. D. Olver, *Corrugated Horns for Microwave Antennas. IEEE Electromagnetic Waves Series*. London, U.K.: Peregrinus,1984.

[13] P.-S. Kildal and E. Lier, “Hard horns improve cluster feeds of satellite antennas,” *Electron. Lett.*, vol. 24, pp. 491–492, Apr. 1988.

[14] B. A. Munk, “Balun, etc.,” in J. D. Kraus and R. I. Marhefka, *Antennas: For AN Applications, Third Edition,* New York, McGraw-Hill, 2002, pp. 803-826.

[15] R. T. Lee and G. S. Smith, “A Design Study for the Basic TEM Horn Antenna,” *IEEE Antennas and Propagation Magazine,* 46, 1, February 2004, pp. 86-92.

[16] R. T. Lee and G. **S.** Smith, **“A** Design Study for the Basic TEM Horn Antenna,” IEEE International Symposium on Antennas and Propagation *Digest,* **1,** Columbus, Ohio, June 2003, pp. 225-228.

[17] Sergei P.Skobelev and Per-Simon Kildal, “Analysis of conical Quasi-TEM Horn with a hard corrugated section” ,*IEEE Transactions on Antennas and Propagation,* vol 51,No.10,Oct 2003.

[18] *Majid Manteghi and Yahya Rahmat-Samii, “*A Novel UWB Feeding Mechanism for the TEM Horn Antenna, Reflector IRA, and the Vivaldi Antenna”, *IEEE* Antennas and Propagation Magazine, Vol. 46**,** No. 5**,** October 2004.

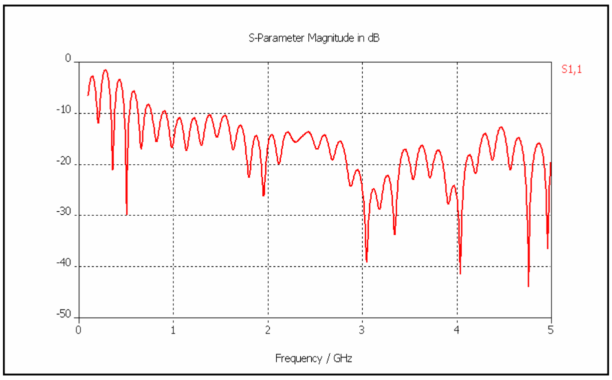

Fig. 3 The magnitude response of the UWB TEM horn antenna

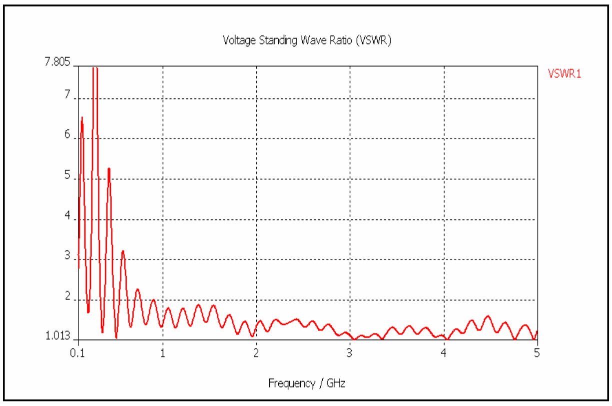

Fig.4 The VSWR response of the UWB TEM horn antenna

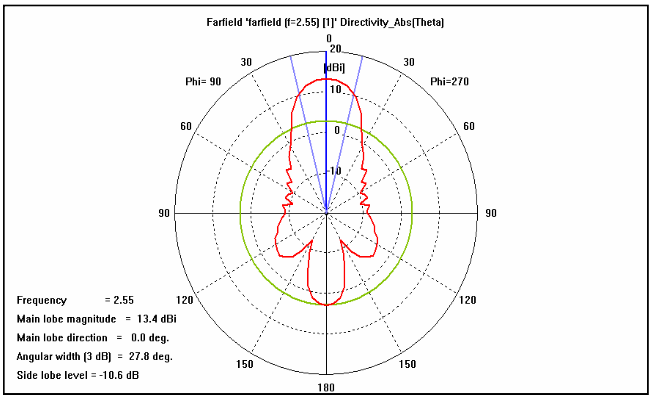

Fig. 5 Directivity of the UWB TEM horn antenna

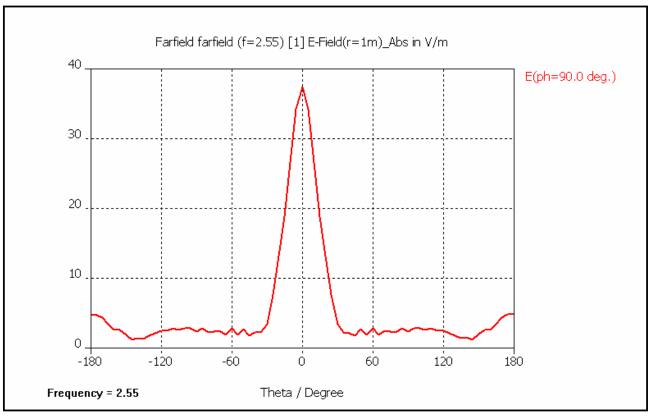

Fig. 6 The E-plane far-field response of the UWB TEM horn antenna

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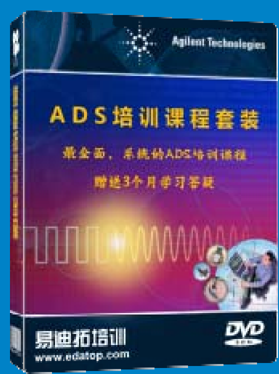

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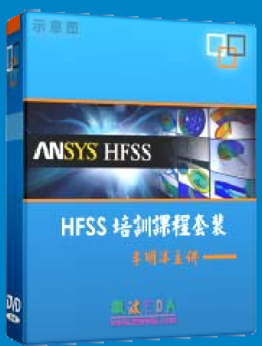

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